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The research completed under this grant provides an understanding of blue stragglers, partial calibration of the Stromgren uvby and Hβ photometric systems, and some initial results concerning the nature of horizontal branch and post-horizontal branch evolution of Population II stars.



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FINAL REPORT

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STUDY OF STELLAR ATMOSPHERES

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AD 740675

Considerable progress was made in several areas of research which received partial support through this grant. This program is summarized below.

1) The Study of Blue Stragglers

This area of research is perhaps the easiest to discuss. Over the past 2 years, Stromgren 4-color and Hβ photometry was obtained for a number of blue stragglers in the intermediate-age galactic cluster NGC 7789. In addition, image tube spectrograms of four of the brightest blue stragglers in this cluster were taken in order to provide data on possible radial velocity variations. By comparing the Stromgren photometric indices with model atmospheres and with observations of well-established cluster sequences, it was possible to conclude that blue stragglers had masses identical to those expected of stars on the main sequence occupying the same location in the (luminosity-effective temperature) plane. This result ruled out the possibility that blue stragglers might be on or near the main sequence for the second time during their evolutionary history. The spectroscopic data provided evidence, in all four of the well-studied cases, in favor of radial velocity variations. We interpret these observations to mean that blue stragglers are the presently visible components of binary systems in which mass exchange has increased the mass and luminosity of the initial secondary (the primary becoming a white dwarf). The results of this study will appear in a paper to be published in the November 1970 Astrophysical Journal. Further support for these results comes from the independent observations of Deutsch and by Deane Peterson of variable velocity among the blue stragglers in the galactic cluster M67 and some recent work by Howard Bond on field Pop II stars which appear to be analogous to the Pop I blue stragglers.

2) Calibration of the ubvy and Hβ Photometric Systems

In the paper concerning the blue stragglers cited above, model atmosphere calibrations of Stromgren's ubvy and Hβ photometry are reported. These calculations were carried out with the assistance of Fred Chromey who initiated work on this project while I was still at Harvard. In the spectral range from early-B to early-A, we regard the transformation between $c_1$ and effective temperature and β and surface gravity to be quite reliable. The computations for stars of later spectral type permit differential comparison of program star vs. standard $c_1$ values to obtain differential surface gravities, and similar comparisons for β and b-y to obtain effective temperatures. Currently, Michel Breger of our staff at Stony Brook and Duane Carbon, who will be joining us in February, are collaborating with me in calculating a grid of blanketed model stellar atmospheres. This grid should permit an absolute calibration of this and other photometric systems in the very near future. By using techniques already reported by Kurucz and Strom and by Gingerich and Carbon, we expect this program to be completed within the next year or so and to include the effects of variations in abundance and in atmospheric turbulence. Actually, we have already made use of some of the blanketed models computed for this program in order to interpret the Stromgren photometry of the Hyades and Pleiades clusters. A collaborative effort between Fred Chaffee and Duane Carbon of the Smithsonian Astrophysical Observatory and myself is currently in the final stages of preparation. The results of this investigation demonstrate the relative roles played by H and He abundance differences, as well as turbulence and metal abundance changes. Most if not all of the difference in the Stromgren 4-color diagrams between the Hyades and Pleiades clusters seems to arise from a combination of metal abundance and age.

3) The Mass of Pop II Stars

In our initial proposal, we indicated the importance to the problem of determining the cosmic helium abundance of knowing the mass of stars at the turnoff point in globular clusters. In addition, we indicated the importance of determin the mass ratio between the horizontal branch and the stars near the turnoff point, both in regard to the He problem and to more general problems such as the nature of horizontal branch star evolution and understanding the pulsation of RR Lyrae stars.

Over the past year we have made a concerted effort to study these problems. The determination of the absolute mass of the stars at turnoff is an extremely difficult problem involving several critical transformations. First the observed visual magnitude of the stars at the cluster turnoff must be converted to luminosity; this involves accurate determination of the cluster distance modulus and a Bolometric correction. Then observations of the Balmer discontinuity and the slope of the Paschen continuum must be translated into surface gravities and effective temperatures. These in turn, require accurate knowledge of the absolute spectral energy distribtution of the stars involved, as well as accurate model atmospheres. The rewards of obtaining an accurate measure of the absolute mass would of course be an immediate test of Pop II helium content, so that the effort is certainly worth making.

A somewhat easier problem -in which the dependence upon the absolute stellar energy distribtuion and the distance modulus is removed, is that of determining the mass ratio between horizontal branch stars and the turnoff point stars. Here a difference of Balmer discontinuity between stars of roughly similar temperatures will yield a surface gravity difference, whereas a luminosity difference can be obtained by using the measured apparent magnitudes and the (small) differences computed for the bolometric corrections between stars on the horizontal branch and the turnoff.

During the part year it became evident that in order to explain the observed color spread for globular cluster horizontal branches, it appeared necessary to invoke a spread in horizontal branch star mass. In the case of the most metal-poor clusters this mass spread amounted to a range of masses between .5 and .85 solar masses. It became obvious that our program to determine masses in globular clusters should include an effort to obtain the ratio of masses on the red and blue ends of the horizontal branch. This effort unfortunately requires somewhat more accurate descriptions of the model atmospheres for these stars as small differences in line-blanketing effects are sufficient to render interpretation difficult.

Through the courtesy of the staff at the Mount Wilson and Palomar Observatories, we were granted access to six nights of dark time on the 200" in order to study the problems outlined above. The Oke multichannel scanner was used to obtain spectral energy distributions of approximately 15 stars near the turnoff in M92 and M15 and a similar number of horizontal branch stars. This data was obtained at the end of August and is currently under interpretation. We expect to complete the model atmosphere calculations necessary to interpret the observed spectral energy distributions during the next year. The difficulties of course, are wrapped up in the proper treatment of the line-blanketing problem which will receive increasingly vigorous attention.

In the course of this program we naturally became involved in many fascinating sidetracks. The most interesting appears to revolve about the evidence we have acquired in favor of extensive mixing of some asymptotic giant branch members of two of the most metal-weak clusters known, M92 and M22. Corresponding evidence concerning the presumed hot descendents of these asymptotic giant branch stars has been found among members of M3 and M10. A detailed spectroscopic study of the asymptotic giant branch and the initial red giant branch was carried out for the cluster M92. Approximately twenty-five spectrograms of stars on these branches were obtained using the image tube spectrograph at Kitt Peak National Observatory. Three of the stars in our study of M92 and three additional stars found in M22 seem to show enormously strong CN and CH features compared to the other giants in the cluster and indeed these features compare with field stars of Pop I in the same temperature range! Moreover, in some of the stars, it appears as if many of the metallic line features are as strong as those found for Pop I stars. These stars are most certainly members of the cluster since the radial velocities we obtain allow virtually unambiguous membership determination. We propose tentatively that these stars are currently in the double shell source phase of their evolutionary history; we suggest that extensive mixing and possibly the loss of most of the outer hydrogen envelope has taken place during this phase. In particular we envision that the light element abundances have been enhanced by mixing with the interior and that the current envelope helium abundance may be very low. The plausibility of such events finds partial encouragement from the theoretical standpoint, particularly from the calculations of Schwarschild and his collaboraters. They suggest that during the asymptotic giant branch (double-shell source) phase of the stars evolution, a thermal instability, resulting from the presence of the two shell sources, may lead to large-scale mixing. However, at present, their hydrodynamic treatment does not indicate that the stars are likely to mix. Nevertheless, the observational evidence seems quite clear in this regard. The hot descendents of these stars also appear to show abundance anomalies. In particular, the work reported by Strom and Strom in the January 1970 Astrophysical Journal concerning VZ 1128 in M3 and later work reported in Astronomy and Astrophysics, October 1970 by these same authors for M10 I 33 suggests that both these early-type stars have high atmospheric abundances for the light elements. Thus it appears that we are witnessing extensive mixing and possibly mass loss among Pop II stars. Further study of stars of this type may yield important dividends in understanding the very early nuclear history of the galaxy. The implications for similar stars in Pop I will be discussed later in this proposal.

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